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Experience with Calibration Procedures for LIPP Test Set-up, Using Solid Calibration Specimens.

M. HENRIKSEN*, J.T. HOLBØLL* and R. J. FLEMING**

*) Electric Power Engineering Department, Technical University of Denmark, Building 325, DK-2800 Lyngby, Denmark

**) Department of Physics, Monash University, Clayton, Victoria 3168, Australia

Abstract

This paper describes the short and the long term behaviour of two different materials that have been suggested for calibration of space charge measuring systems. Two different space charge measuring systems were planned to be used for the investigation, more specifically, the laser induced pressure pulse (LIPP) system and the pulsed electroacoustic (PEA) system.

The material used for the calibration test was 100μm thick corona charged PET (Mylar) film. It was concluded that such film is unlikely to be useful for calibration purposes.

Introduction

For all practical measurements of space charges in electrical high voltage insulation, it should be recognised that it is very important to record the following material parameters: production conditions, storage, preconditioning of the sample, test temperature, test temperature variations, type of electrical stress applied, duration and magnitude of electrical stress applied to the sample before and during testing, and superimposed stress applied to the sample during the test (LIPP ~ laser energy, rise time and width of laser pulse; PEA ~ size, rise time and width of pulse, polarity of pulse, etc.).

It is often very difficult to compare space charge data published by different laboratories world-wide. This situation has developed because, although the LIPP and PEA techniques are now well-established, experimental conditions such as those listed above have not yet been comprehensively and clearly prescribed by the appropriate international technical organisations.

In recognition of this fact, IEEE and Cigré have decided to investigate the different experimental methods of measuring space charge distributions, and to evaluate their accuracy and reliability.

More specifically, the aim of the work of the IEEE-DEIS 32-13(Space Charge in Solid Dielectrics) is[1]:

1. To determine the space charge physical parameter: trap nature energy and cross section, variation of the trapping cross section as function of the electrical field, of the temperature and of mechanical stress, effects of the trap charges on the insulation internal energy, material charge storage capability, energy relaxation processes, energy released during charge detrapping, defect generation, charge propagation.
2. To evaluate the ability of techniques to measure these various parameters.
3. To link the physical parameters with what is observed during breakdown: time to breakdown, dielectric transition temperature, size factor, etc.
4. To demonstrate to what extent the material intrinsic charging parameters determine the system performance.
5. To evaluate on what system (thin film, powder, pellets, piece of cable, etc.) the various techniques can be applied.

The scope of the work of Cigré SC 15, TF3 (Space Charge Measurements)[2] is

1. The measurement of space charge in electrical insulation systems.
2. Space charge measurement techniques.
3. The characteristics of the different techniques.
4. Evaluation of the obtained test results from the different measurement systems.

This work may include the identification of one or more dielectric materials suitable for calibrating and comparing the various space charge measurement techniques.

The final goal for both groups is to produce suggestions for calibration methods to be adopted by both the IEEE and the IEC, leading to international standardisation.

The initial tasks of the Cigré SC 15, TF3 (formed in 1996) are:

- to prepare a state-of-the-art report on space charge measurements for ELECTRA
- to prepare a checklist of good measurement practice
- to develop and carry out a Round Robin Calibration.

This paper deals with our findings in relation to the ongoing Round Robin calibration Test (RRT) when applying a PEA test system and a LIPP test system.

Calibration

The instrumental parameters of the existing space charge measuring systems are not sufficiently well known to give space charge densities directly. Calibration runs need to be performed for each test sample.

It would therefore be ideal if there existed a test specimen or specimens containing a standard bulk volume charge to be used for the individual instrument calibration. One of the obvious requirements would be a test specimen (insulation material) containing a well defined bulk charge with respect to magnitude and location, and with long term stability.

As such a calibration specimen does not exist at the present time, the common approach has been to apply surface charges to a test sample by application of a known electrical stress across the test specimen. Knowing the applied voltage and measuring the corresponding surface charge, the system is assumed to be calibrated, by assuming that it is possible to extrapolate from the measured surface charge to the later measured bulk charge. This test method assumes that there are no bulk charges in the test specimen, and, at the same time, it is assumed that the applied calibration voltage is not forming any bulk charge during calibration. Thus the applied electrical stress must not exceed 5kV/mm approximately. One also has to assume that the bulk charge can be directly related to the surface charge recorded on the electrodes during the calibration,. One very important question here is whether the initial calibration remains valid for a test specimen undergoing long term ageing, which could lead to water absorption, oxidation, etc. An essential check is to integrate the product of the measured charge density $\rho(z)$ and z across the thickness of the test specimen. This will yield the electric field $E(z)$ and hence the potential difference across the specimen, which should equal the applied voltage.

With the above listed reservations, regarding calibration of a space charge measuring systems based on an observed surface charge on the electrodes, Cigré SC 15, TF3 decided to commence an RRT of two possible insulating materials containing a known stable bulk charge. These two materials were a 100μm thick corona charged PET (Mylar) film, and a 2mm thick electron beam irradiated PMMA (Plexiglass) sheet.

Experiments

We had planned to report in this paper the results of PEA and LIPP measurements on 2mm thick electron beam irradiated PMMA samples. Unfortunately the electron accelerator failed to operate reliably at beam energies below 1MeV, and this part of our investigation has therefore been postponed. However we have investigated corona charged PET films, using our LIPP systems with a spatial resolution not exceeding 30μm. (At the present time the spatial resolution of our PEA system exceeds 50μm which is why a 100μm PET film could not be tested in this system). The LIPP test results are presented below.

Initially we attempted to test all the films for the presence of space charge in the bulk. Very little charge was found in all samples, but quantification proved extremely difficult, because of screening by surface charges which we could not eliminate.

Experiments were performed on six different PET samples all 0.1mm thick. In this paper is reported test data from four of the samples, 11D, 18A, 18B and 18D. The sample surfaces were first cleaned with a cotton ball containing alcohol, after which the samples were placed in a vacuum chamber for ten minutes. A gold-leaf measuring 2×2 cm was placed on one surface of each sample, to act as the high voltage electrode.

Each sample was short-circuited to ground for a minimum of 24 hours at room temperature before a voltage was applied. A 1mm thick semicon electrode, 32mm in diameter, was then attached to the other surface of the sample, and acted as the ground electrode and the target for the laser beam. A sketch of the sample ready for voltage application is shown in figure 1. The gold-leaf electrode could be made positive or negative with respect to ground.

The test sequence was as follows:

1. Determine the amount of space charge in the virgin sample using a laser energy of 34mJ (single shot) applied evenly to a circular area of the semicon electrode 6mm in diameter (see Figure 3).

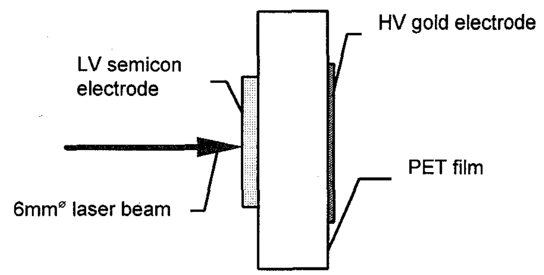

Figure 1: Electrode layout for PET sample.

2. Perform a calibration at various applied field strengths up to a maximum of 6kV/mm, since our experimental results indicated zero charge injection at such fields. A typical calibration curve, in which the amplitude (volt) of the LIPP signal from the charge on the ground (semicon) electrode is plotted against the charge density pC/cm^2 on that electrode, is shown in Figure 2.
3. Measure the charge density in the bulk as a function of time while a constant electric field of +20kV/mm is applied, and during a subsequent period of grounding.
4. Apply a field of -20kV/mm, and repeat 3.

The results of such a test cycle (3. & 4.) performed on one of the four test specimens are shown in Figure 4.

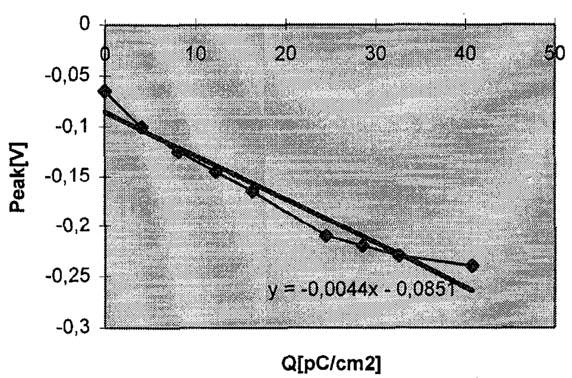

Figure 2: Charge density calibration curve for PET sample, The heavy straight line is a least squares best fit to the experimental data.

Discussion of Results

Recordings of possible bulk charge in virgin test samples are shown in Figure 3: In the first trace on this figure is shown the recorded signal with a voltage of 2kV applied to a test specimen in order to identify the test electrodes

(performed after the initial space charge location test). This is done in order to identify the location of a possible space charge in a test specimen.

The following four traces are recordings of the virgin samples 11D, 18A, 18B and 18C, in short circuit, followed by a calibration and before 20kV/mm was applied. The traces show very little, if any, bulk space charge. Similar findings for nominally identical samples have been reported by a group of Japanese test laboratories[3].

The top trace in each column of Figure 4 was recorded for sample 11D immediately after +20kV/mm or -20kV/mm had been applied. The other traces were recorded in short circuit at various times thereafter. The sequence was +20kV/mm for 1h, short-circuiting to ground for 16h, -20kV/mm applied for 1h, and short-circuiting to ground for 16h. The results are surprising in that very little charge decay, if any, is observed following short-circuiting after +2kV had been applied, but a complete disappearance following short-circuiting after -2kV had been applied. More importantly, there is no indication of a charge, fixed in position and of constant magnitude, which could be used for calibration purposes. The use of different electrode materials (gold and semicon) may have had some influence[4], but further work is required to clarify this.

Conclusion

Although we have at present relatively few data, and the spatial resolution of the measurements is large compared to the sample thickness, we conclude that

a) there is probably very little space charge in the bulk of these PET samples, and

b) they are unlikely to be useful for calibration purposes.

References

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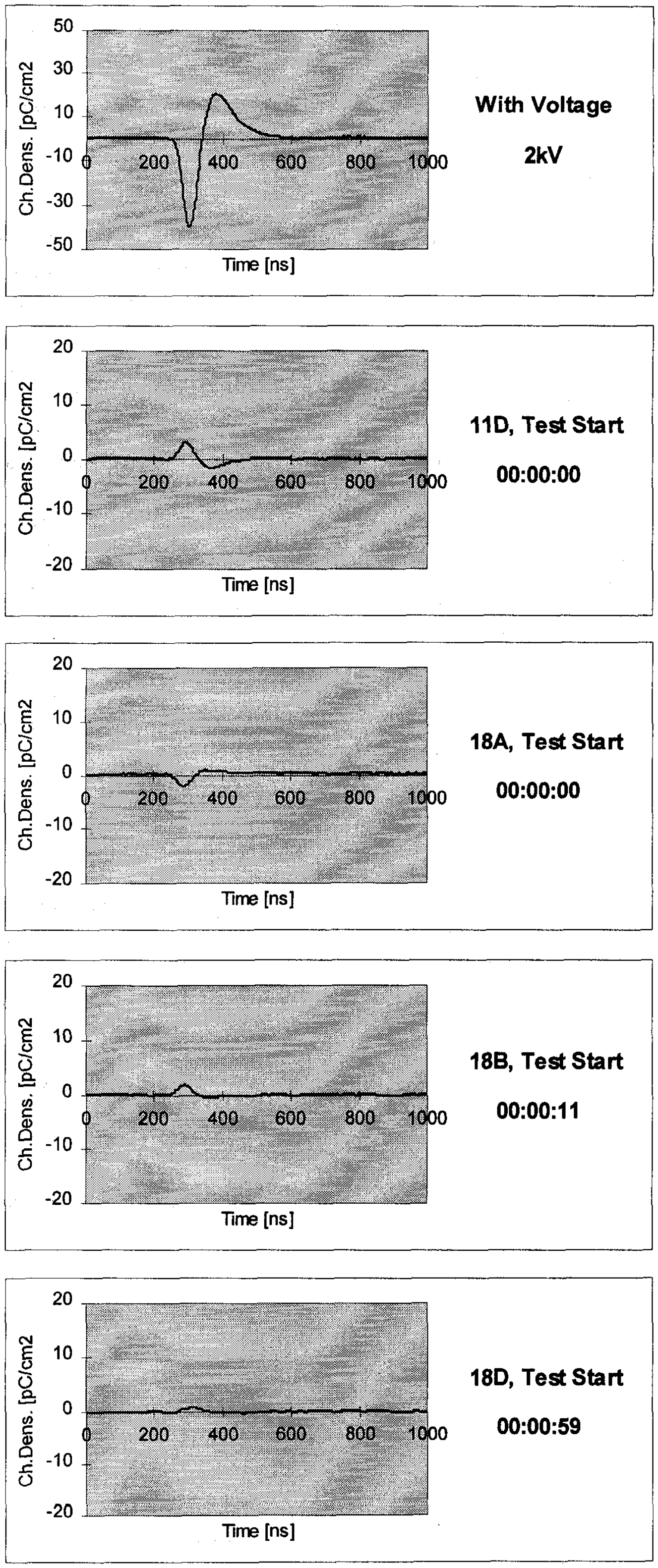

Figure 3:

Top Trace - Identification of test electrodes, 2kV applied to sample.

Other Traces - Initial Bulk charge measurement recorded in short-circuit.

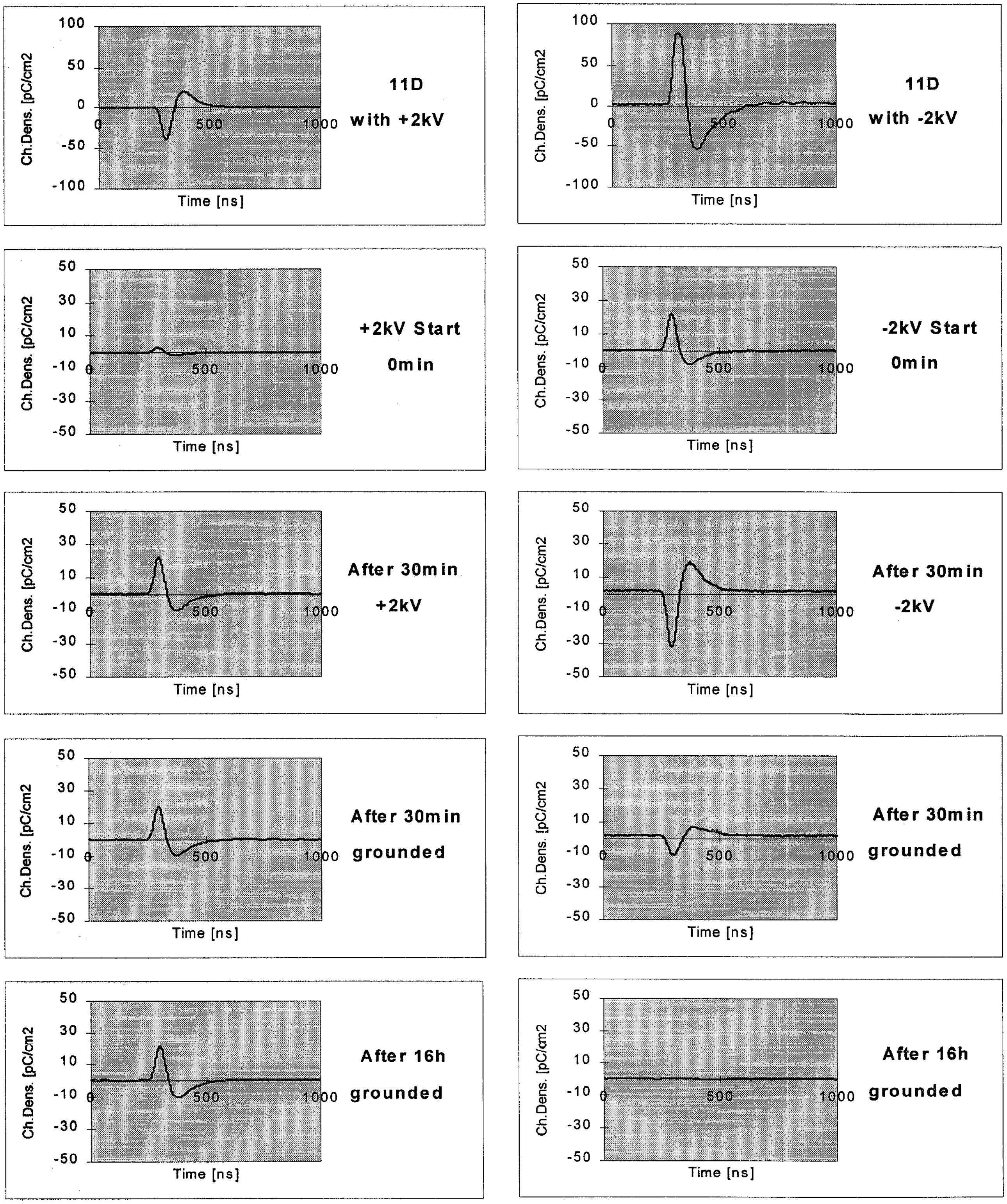

Figure 4: +20kV/mm for 1h, → grounding for 16h, → -20kV for 1h, → grounding for 16h.